

# NASA Game Changing Development Program Manufacturing Innovation Project

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This presentation examines the new NASA Manufacturing Innovation Project. The project is a part of the Game Changing Development Program which is one element of the Space Technology Programs Managed by Office of the Chief Technologist. The project includes innovative technologies in model-based manufacturing, digital additive manufacturing, and other next generation manufacturing tools. The project is also coupled with the larger federal initiatives in this area including the National Digital Engineering and Manufacturing Initiative and the Advanced Manufacturing Partnership. In addition to NASA, other interagency partners include the Department of Defense, Department of Commerce, NIST, Department of Energy, and the National Science Foundation. The development of game-changing manufacturing technologies are critical for NASA's mission of exploration, strengthening America's manufacturing competitiveness, and are highly related to current challenges in defense manufacturing activities. There is strong consensus across industry, academia, and government that the future competitiveness of U.S. industry will be determined, in large part, by a technologically advanced manufacturing sector. This presentation highlights the prospectus of next generation manufacturing technologies to the challenges faced NASA and by the Department of Defense. The project focuses on maturing innovative/high payoff model-based manufacturing technologies that may lead to entirely new approaches for a broad array of future NASA missions and solutions to significant national needs. Digital manufacturing and computer-integrated manufacturing "virtually" guarantee advantages in quality, speed, and cost and offer many long-term benefits across the entire product lifecycle. This paper addresses key enablers and emerging strategies in areas such as:

- Current government initiatives
- Model-based manufacturing
- Additive manufacturing



# NASA Game Changing Development Program Manufacturing Innovation Project

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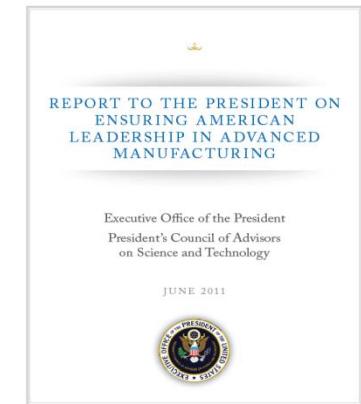


# Manufacturing Innovation – Critical to National Needs

NASA Game Changing Development Program

Manufacturing Innovation Project

- Carnegie Mellon University, June, 2011 -- President Obama called for the federal government to increase support for manufacturing technology. "If we want a robust growing economy, we need a robust manufacturing sector," Obama said, announcing the "Advanced Manufacturing Partnership."
- "We cannot remain the world's engine of innovation without manufacturing activity," the President's Council of Advisors on Science and Technology told the President in a report released with the speech. "The Nation's historic leadership in manufacturing, however, is at risk."
- Twenty years ago, as the U.S. consumer manufacturing sector suffered a near-death experience in the face of Japanese innovations, the MIT report "Made in America" concluded that, "To live well a nation must produce well." Is this still true today? What now lies ahead in this world of globalization, open innovation, biology-based manufacturing, and next-generation robotics?



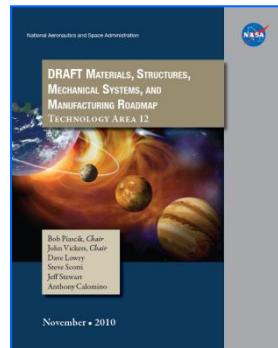
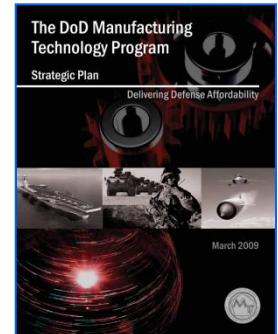
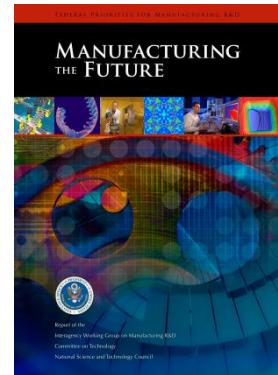


# Manufacturing Innovation – Critical to National Needs

## NASA Game Changing Development Program

## Manufacturing Innovation Project

- The Interagency Working Group (IWG) on Manufacturing Research and Development (R&D) ; March 2008 “Manufacturing the Future -- Federal Priorities for Manufacturing Research and Development”
  - Intelligent and integrated manufacturing is fundamental to the advanced manufacturing operations and organizations of tomorrow.
- The DOD Manufacturing Technology Program Strategic Plan
  - “...collaborative design environment between engineering and design, production and test, and the manufacturing supply chain...a highly integrated design for manufacturability capability, increased fidelity cost modeling, pre-production test and validation, and first article quality.”
- The NASA technology area (TA) roadmap for Materials, Structures, Mechanical Systems and Manufacturing
  - The roadmap introduces an advanced long term concept (vision), Virtual Digital Fleet Leader (VDFL) (a.k.a. Digital Twin), that addresses multiple technology needs

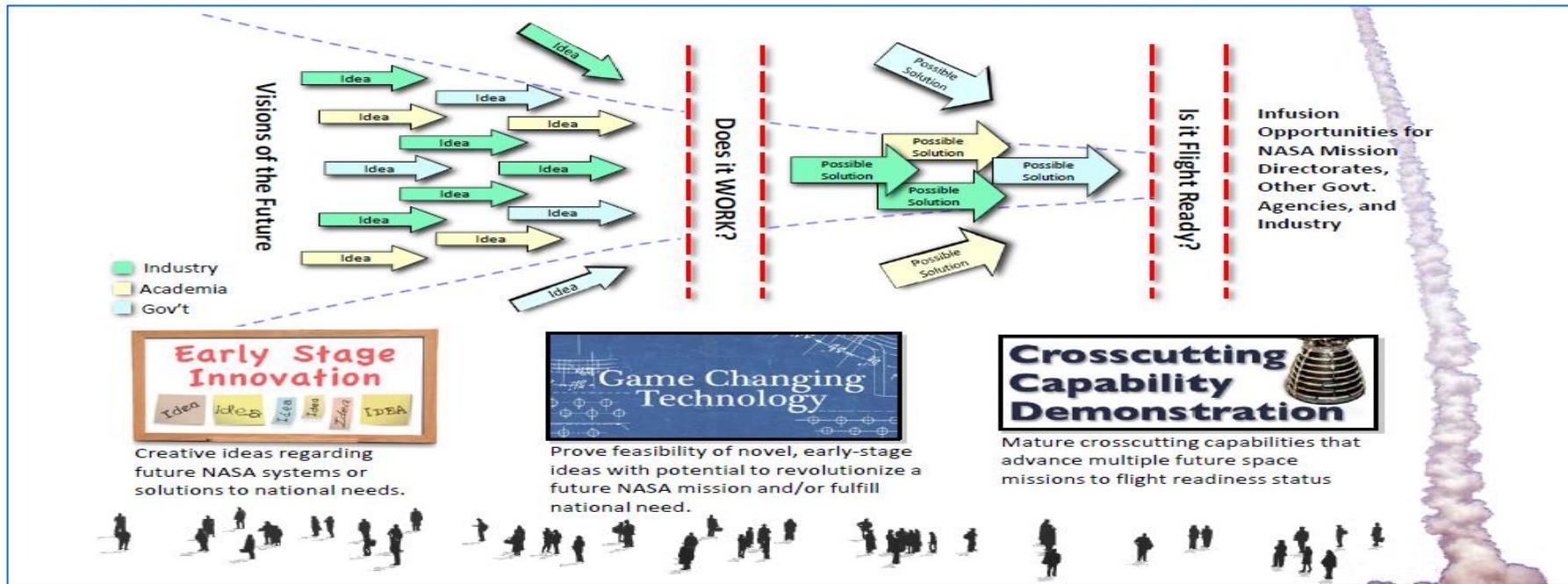




# Space Technology Program Approach

## NASA Game Changing Development Program

## Manufacturing Innovation Project



Cornell Professor Mason Peck, who takes over NASA's Office of the Chief Technologist in January 2012.

"It's key to recognize that innovation drives economic success. It inspires people, it provides new directions for new businesses, and that's always been the case. We're lucky that Congress agrees with the president that NASA needs this kind of technology program. It provides innovation that creates jobs, stimulates the economy -- and for NASA particularly, provides a path for NASA's future."



# The Game Changing Program

NASA Game Changing Development Program

Manufacturing Innovation Project

## What is our Mission?



*To focus on transformative space technologies that will lead to advances in space and terrestrial capabilities, serve as a stimulus to the US economy while providing inspiration and opportunity to our nation's youth*

### Goals

- Develop Game Changing technologies that produce dramatic impacts for NASA's Space Exploration and Science Missions
- Capitalize on opportunities to leverage funding and cost-share from external organizations in technology areas mutually benefiting NASA and the other organizations
- Formulate and implement technology projects that deliver the required performance to stakeholders on schedule and within cost
- Deliver technology knowledge that is used internally for NASA missions as well as externally throughout the aerospace community



# The Game Changing Program

NASA Game Changing Development Program

Manufacturing Innovation Project

## How Do We Define Game Changing?



- *Shifts the way we approach an existing capability (Enhancement)*
  - Cost
  - Size
  - Performance
  - Simplification
  - Impact upon overall system
- *Creates a new capability (Enabling)*
  - Replaces one or more existing capabilities
  - Creates new possibilities and new missions
  - Quickly becomes the new norm
- *Impacts a technology portfolio (Disruptive)*
  - Narrows
  - Prioritizes
  - Shifts
  - Creates
- *Impacts our concept of systems (Disruptive)*
  - New trades
  - New freedoms
  - More adaptable and robust



# Manufacturing Innovation Project

NASA Game Changing Development Program

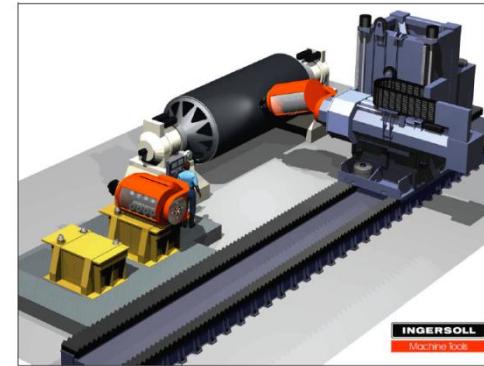
Manufacturing Innovation Project

**Project Manager:** Carol Tolbert

**NASA Glenn Research Center**

**Principal Investigator:** Keith Belvin

(LARC, GCDP)



**Conceptual Design Verification  
Through Simulation**

**Big Idea:** Accelerate Innovative Approaches to Model Based Digital Manufacturing (MBDM) within NASA and Spin-off to Industry

**Approach:** Leverage in-house Tech Development/Capabilities with High-payoff Partnerships with Government, Industry and Academia

**Concept:** Collaborate through the Interagency Competitiveness Initiative, promote innovative & revolutionary approaches to manufacturing

**Goal:** Dramatically Improve manufacturing through modeling and simulation and cyber-physical systems contributing to the NASA Mission and revitalizing the nation's manufacturing sector

*Manufacturing Problems Solved Before They Happen...*



# Manufacturing Innovation Project

## NASA Game Changing Development Program

## Manufacturing Innovation Project



**EBF<sup>3</sup> Electron-Beam Freeform  
Process Fabrication Demonstration**

### Major Milestones

1. Identify and design functional aerospace parts for additive manufacturing test cases
2. Develop process simulation models for thermal additive manufacturing deposit geometries
3. Fabricate finished tensile bar, for S-Basis work, produced from net shape part using Direct Digital Manufacturing processes with minimal human interaction
4. Complete test article production for determining S-Basis allowables of the EBF<sup>3</sup> and EBMRP processes
5. ISS ECLSS or similar functional parts produced, inspected, machined and tested
6. Establish partnerships and outreach activities to support economic development in the Glenn Research Center geographic region

### Project Scope

Advance manufacturing technologies that will enable NASA's future space exploration activities

Demonstrate advanced additive manufacturing

- Process modeling and validation supported by testing
- Materials properties testing to NASA requirements
- Integrated Manufacturing Process Modeling & Simulation
- Production and test of representative aerospace component

Establish public-private advanced manufacturing technology partnerships/consortia

Enhance regional manufacturing innovation, economic vitality, and educational opportunities

### Resources

Total	Budget (\$M)	FY12	FY13	FY14
GRC		3.0	3.0	3.0
LaRC				
MSFC				



# Manufacturing Innovation Project

## NASA Game Changing Development Program

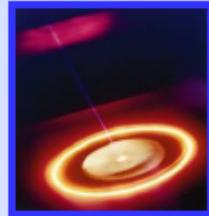
### STATUS QUO

- State-of-the-art aerospace manufacturing addresses reliability and safety with significant challenges to reduce cost and mass
- Carrying numerous spare parts into space is impractical
- Current economic assessment identifies Cleveland, OH as a distressed city



### NEW INSIGHTS

- Enhancements to sensing technology enables modeling of as-built parts
- Additive Manufacturing techniques may be suitable for metallic aerospace parts
- OSTP & NASA establishing manufacturing partnership



### PROBLEM / NEED BEING ADDRESSED

- Revitalize US manufacturing by improving competitiveness in the global economy.
- Rapid fabrication of certifiable, affordable parts for ground & in-space manufacturing, for NASA missions

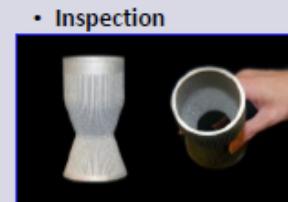
### PROGRAM DESCRIPTION:

Addressing today's challenges in advanced aerospace manufacturing innovation in three primary areas:

- Establishment of public-private advanced manufacturing technology partnerships/consortia
- Use of model-based manufacturing and modeling & simulation within manufacturing
- Additive manufacturing

Challenges: Integrate System-of-Systems elements

- Physics base modeling
- Autonomous machining
- AM processes



#### Critical Technologies:

- Modeling and Simulation
- Sensing
- Additive Manufacturing (EBF<sup>3</sup>, EBMRP)
- Materials and AM processes suitable for final parts

#### Approach:

- Integrate modeling, simulation, and direct digital manufacturing techniques & processes, then build, finish, test, & validate manufacturing approach
- Establish partnerships to support economic development in the GRC geographic region

## Manufacturing Innovation Project

### QUANTITATIVE IMPACT

- Leads to manufacturing capability beyond low earth orbit, little/no human interaction
- Manufacture reliable parts faster with reduced cost, mass
- Using DDT&E methodology, demonstrate AM parts can be certified for space flight
- Enhanced regional manufacturing innovation, economic vitality, and educational opportunities

### PROGRAM GOAL

- Integrate digital manufacturing techniques to machine net shape part to finished shape



- Fabricate, qualify functional aerospace parts using additive manufacturing
- Establish partnerships & outreach activities to support economic development in the GRC geographic region

Competitiveness of US Industry, and success of future NASA missions requires Advanced Manufacturing (AM) technology



# Manufacturing Innovation Project

## SC2 Strong Cities Strong Communities

NASA Game Changing Development Program

Manufacturing Innovation Project

**SC2**

- Midwest Project
- Automotive Workshop
- Adopt a City Initiative
- Think Box
- SPACE
- Tech Shop

- **SC2 Obama Administration pilot initiative to:**
  - Spark economic growth in local communities**
  - Ensure taxpayer dollars are used wisely and efficiently**
- **6 Pilot cities identified for the Initiative:**
  - Chester, PA.**
  - Cleveland, OH.**
  - Detroit, MI.**
  - Fresno, CA.**
  - Memphis, TN.**
  - New Orleans, LA.**



# Manufacturing Innovation Project

## SC2 NDEMC Midwest Project

NASA Game Changing Development Program

Manufacturing Innovation Project

**SC2**

- NDEMC Midwest Project
- Automotive Workshop
- Adopt a City Initiative
- Think Box
- SPACE
- Tech Shop

\*EDA \$2,000K  
\*\*OEMs \$2,500K



OEMs – LM, GE, P&G, John Deere, Purdue Univ,  
Regional Initiative: OH., MI., IN, IL.

White House announced NDEMC Consortium, March 2, 2011  
(Nat'l Digital Engineering & Manufacturing Consortium)



NASA - Providing MDAO S/W for improved standards and design methods

MDAO (Multi Discipline Analysis and Optimization) S/W – Provides advanced design methodologies to shorten design time and decrease costs by providing manufacturing solutions earlier in the design life.

\* EDA – Economic Development Administration

\*\*OEM – Original Equipment Manufacturers



# Manufacturing Innovation Project

## SC2 Automotive Workshop

NASA Game Changing Development Program

Manufacturing Innovation Project

**SC2**

- NDEMC Midwest Project
- Automotive Workshop
- Adopt a City Initiative
- Think Box
- SPACE
- Tech Shop



**MAGNET**  
Manufacturing Advocacy & Growth Network

- Director Dr. Giorgio Rizzoni - Ohio State University (OSU) Center for Automotive Research (CAR)
- President Dan Berry - MAGNET (Manufacturing Advocacy and Growth Network)  
Hosting Invitation only workshop @ GRC
- Oct. 27 Automotive Industry Workshop and members dinner @ NASA GRC
- Oct. 28 CAR holding quarterly meeting at OAI
- Over 25 technology exhibits demonstrating the latest NASA technologies to benefit the automotive industry and support local economic development including: *advanced materials, nanotechnology, innovative extreme environment sensors, intelligent control*
  - Features: One-on-one conversations with NASA innovators
  - Discussions on how NASA's R&D could benefit participants
  - NASA specialists on hand to discuss the process of working with NASA



# Manufacturing Innovation Project

## SC2 Adopt a City Initiative

NASA Game Changing Development Program

Manufacturing Innovation Project

**SC2**

- NDEMC Midwest Project
- Automotive Workshop
- Adopt a City Initiative
- Think Box
- SPACE
- Tech Shop

NASA (resources)  
City of Cleveland (resources)  
Cuyahoga County (resources)

**WHAT:** Adopt a City Initiative

To support small & medium manufacturing companies in  
Cleveland /Cuyahoga County

Specific technical challenge with a new or existing product  
If solved quickly, would result in revenue, job creation or no job loss



**HOW:** Non-Reimbursable Space Act Agreement with Cleveland /Cuyahoga County  
Purchasing Agreement with Ohio Department of Development - PR to MAGNET  
8-10 companies awarded city/county funds  
40Hrs. of NASA expertise per winning company

**WHEN:** Media Campaign starts October 24



**MAGNET**  
Manufacturing Advocacy & Growth Network



# Manufacturing Innovation Project

## SC2 Think[box]

NASA Game Changing Development Program

Manufacturing Innovation Project

**SC2**

- NDEMC Midwest Project
- Automotive Workshop
- Adopt a City Initiative
- Think[box] (Prentke/Romich Collaboratory) NASA (resources)
- SPACE CWRU (resources)
- Tech Shop

- **Dr. Malcolm Cooke**
- **Department of Mechanical and Aerospace Engineering**
- **Think[box] Goal:** Create an entrepreneurial environment where ideas can be nurtured, developed, funded, and commercialized.
- **Think[box] Vision:** Change the economic & social culture of the University and region by emphasizing cross-discipline and cross-institution collaborative endeavors that push creativity and innovation to their limits.
- **Think[box] Mission:** Provide a project-based learning environment where students from all courses of study have an opportunity to understand how innovation and creativity can lead to economic and social advancement. This exposure will encourage entrepreneurial thinking among students, who will then be poised to become the leaders and innovators of the future.



# Manufacturing Innovation Project

## SC2 SPACE

NASA Game Changing Development Program

Manufacturing Innovation Project

**SC2**

- NDEMC Midwest Project
- Automotive Workshop
- Adopt a City Initiative
- Think Box
- SPACE (PLM S/W)
- Tech Shop

- **SPACE Strategic Partners For the Advancement of Collaborative Engineering**
- **Dr. Iwan Alexander, Case Western Reserve University, Chair Mechanical & Aerospace Engineering**
- **Dr. Michael Grieves, Consultant to SPACE Project at MSFC, GRC and KSC**
- **Purpose:**
- **Encourage students to engage with STEM**
- **Educate students and allow them to experience the process and digital tools that industry uses in the creation, manufacturing, sustainment, and disposal of products today.**
- **Engage students in realistic and meaningful projects in the space and technology area.**



# Manufacturing Innovation Project

## SC2 Tech Shop

NASA Game Changing Development Program

Manufacturing Innovation Project

**SC2**

- NDEMC Midwest Project
- Automotive Workshop
- Adopt a City Initiative
- Think Box
- SPACE
- Tech Shop



Locations:  
San Francisco,  
San Jose  
Menlo Park  
Detroit, Mi.  
Washington, DC  
Cleveland, OH.  
Brevard County, FL.

**Tech Shop:** For-profit organization offering unlimited usage of its equipment  
Cleveland is on the second tier Tech Shop map to expand

Need \$2M to rent

Staff up for 1 year

About \$100/mo.

15,000 square feet of manufacturing & prototyping equipment

Opportunities for GRC Employees to teach, be a member of the Tech Shop

Why NASA

- Presidential Manufacturing Innovation Agenda
- Supporting surrounding communities
  - ✓ Economic development and job creation
  - ✓ Being a convening partner with various partners
  - ✓ Repositioning NASA on cutting-edge with innovative approaches for inventing technologies



# Additive Manufacturing In the News

## NASA Game Changing Development Program

## Manufacturing Innovation Project

### GE Intensifies Focus on Additive Manufacturing

May 2011

Will achieve dramatic reductions in GE's material needs and enable more advanced product designs across the company's industrial businesses

### 3D Systems Selected By Georgia Tech and DARPA for MENTOR Program

September 2011

Press Release

High Schools Receive Hands-On 3D Printing Experience

Australian researchers are assessing the feasibility of using additive manufacturing to produce small titanium components for the Joint Strike Fighter (JSF). [www.theengineer.co.uk](http://www.theengineer.co.uk)

The world's first '3D-printed' aircraft has successfully taken flight at the University of Southampton, March 2011



### National Academy of Engineering 2011

U.S. Frontiers of Engineering Symposium:  
Additive Manufacturing in Aerospace

September 2011

Benefits of AM will be extended beyond current applications with new materials



Printing a building -- additive manufacturing research moves into construction

November 2011

Additive manufacturing -- commonly known as 3-D printing -- has been used for a surprisingly large range of products and projects, while the devices themselves have continually declined in cost and size; now the technology turns its attention to concrete and building

### Materials Broaden Reach of Additive Manufacturing (designnews.com) August 2011

"Materials are the drivers for growth, always have been," says Todd Grimm, an additive industry veteran and consultant. "Speed and quality are meaningless if material properties can't satisfy an application's needs..."



# Additive Manufacturing - In-Space Manufacturing

NASA Game Changing Development Program

Manufacturing Innovation Project



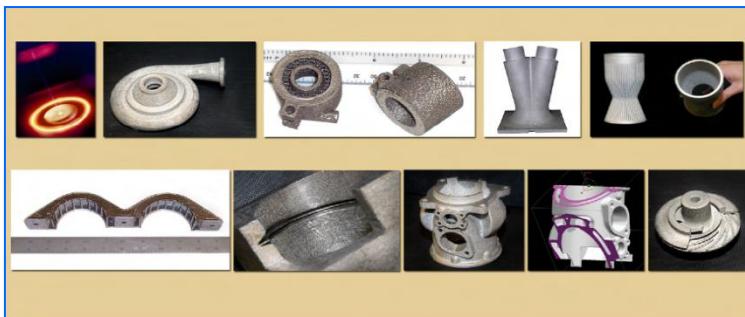


# Additive Manufacturing

NASA Game Changing Development Program

Manufacturing Innovation Project

- The Manufacturing Innovation Project supports these long term goals for additive manufacturing
  - Develop an ability to manufacture, inspect, and finish parts in space with minimal human interaction
  - Develop a process which supports the use of various additive manufacturing processes and materials
  - Build “certifiable” metallic parts using the Electron Beam Melting (EBM) additive manufacturing process
  - Optimize process parameters to give best quality parts
  - Develop automated, intelligent process for inspection and machining of parts
  - Eliminate need for spares; build parts as-needed





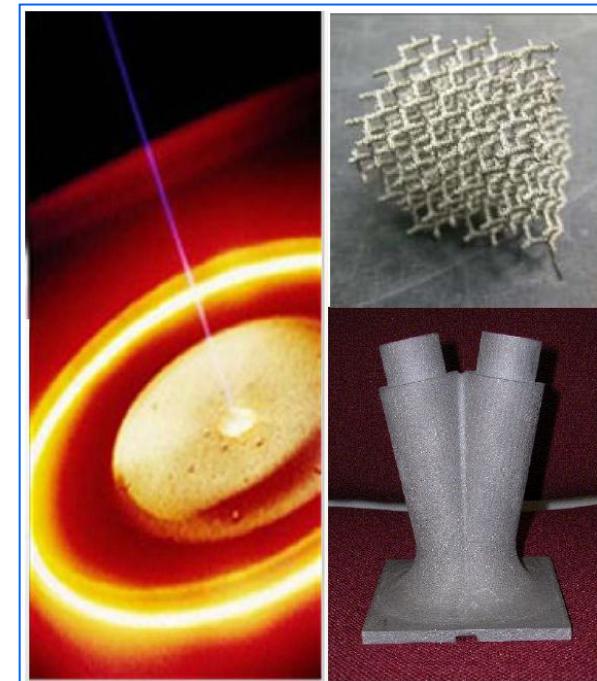
# Additive Manufacturing

NASA Game Changing Development Program

Manufacturing Innovation Project

- **Effort Details**

- **Select candidate part(s) which can be made in the EBM (MSFC) and EBF<sup>3</sup> (LaRC) machines. Ideally pick a part which has a high replacement rate.**
- **Build multiple instances of the part(s) with varying process parameters**
- **Draw correlations between process parameters and mechanical test results**
- **Demonstrate that flight quality parts can be manufactured through additive manufacturing processes**





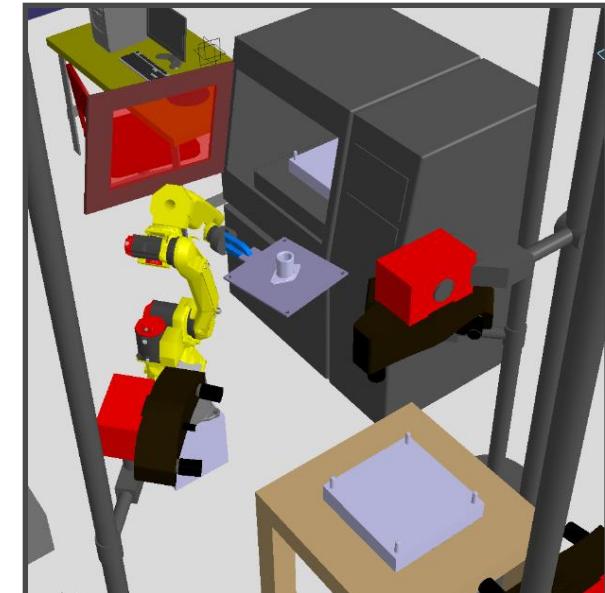
# Additive Manufacturing

NASA Game Changing Development Program

Manufacturing Innovation Project

- **Effort Details**

- Incorporate a structured light scanner and automation equipment
- Manually scan parts, compare to as-designed CAD models, and generate machining tooling paths. Machine parts to bring into conformance
- In parallel, develop methods to automate the manual processes
- Demonstrate that parts can be inspected and machined with little to no human interaction; take astronaut out of the loop



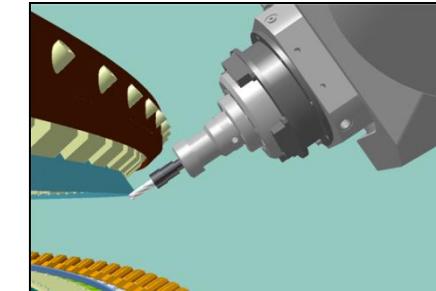


# Modeling & Simulation

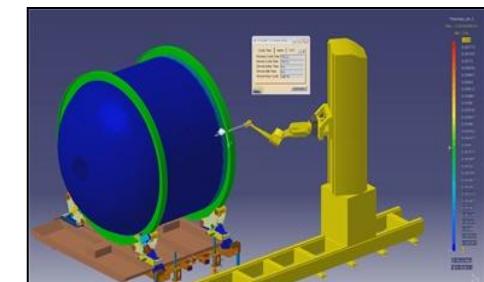
NASA Game Changing Development Program

Manufacturing Innovation Project

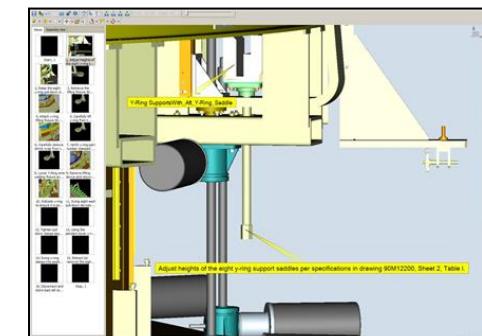
- Focus is to develop a Digital Manufacturing Modeling and Simulation environment
  - Makes manufacturing smarter
  - Works in parallel with the product design
  - Catches problems early
  - Saves time and money
  - Builds off industry standard software tools
  - Captures as-built data record
  - Works with various Product Data Management (PDM) systems, i.e. don't develop point-to-point solutions
  - Simulation capabilities well established
  - Manufacturing Execution System (MES) implementation making good progress
  - Digital Design to Manufacturing (DDTM)



Producibility Analyses



Off-line Programming



Model-Based Work Instructions

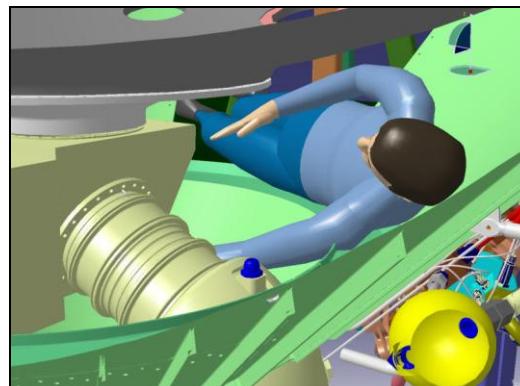
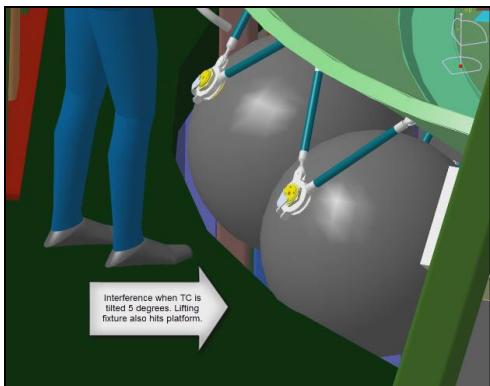
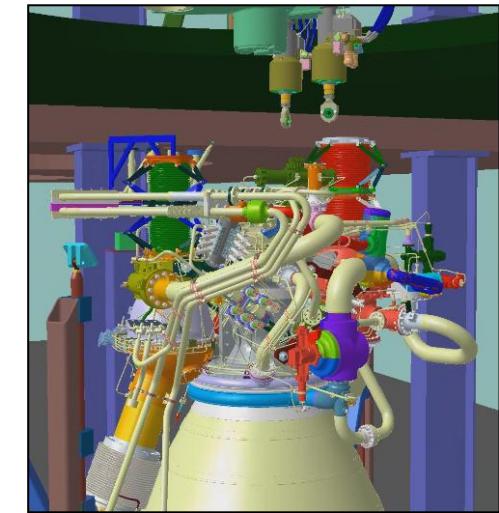


# Modeling & Simulation

## NASA Game Changing Development Program

- **Process Verification Through Simulation (DELMIA Software)**
- **Verification of Facilities**
  - Identification of process flow and assembly problems due to facilities limitations
- **Interference Analysis**
  - Gain understanding of all the interactions between tooling, fixtures, GSE, etc.
  - Simulate assembly processes and identify problems (interferences, violation of keep out zones, pinch points, etc.)
- **Kinematic Verification**
  - Definition of complex kinematic mechanisms, up to 9 degrees of freedom
  - Determine through process simulations whether planned operations are kinematically feasible
- **Off-line Robotic Programming**
  - Optimization of robotic systems in an offline, 3D environment
  - Deliver programs to the manufacturing floor for execution

## Manufacturing Innovation Project





# Digital Manufacturing

NASA Game Changing Development Program

Manufacturing Innovation Project

## White Light Scanning and Photogrammetry

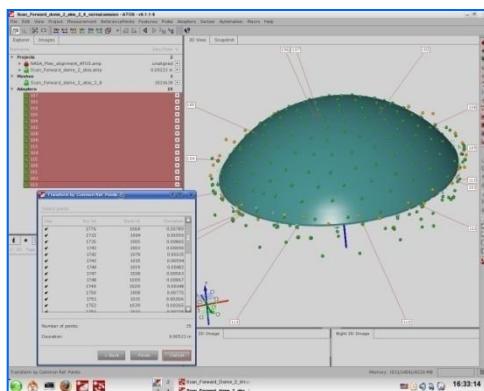
- Critical technology behind the successful Ares I Upper Stage Common Bulkhead



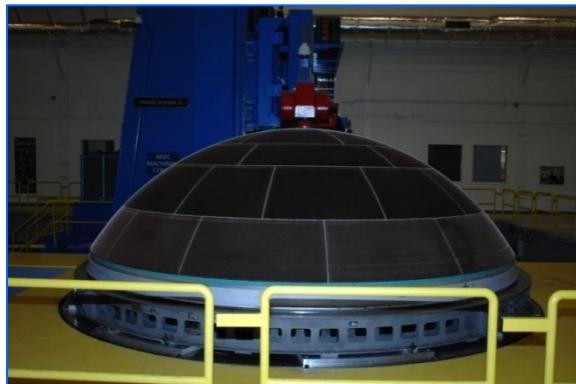
Common Bulkhead  
Forward Dome



Scanning of the Forward Dome



As-Built CAD Model



Develop machine path based on  
as-built model



Successful Bond of Final  
Assembly